

Anomalous $U(1)$ and asymmetry

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Abstract. In the past years many possible extensions of the Standard Model (SM) have been investigated. If one of this model is revealed at the LHC, we will need tools to distinguish it among the many others studied. One possibility to achieve this goal is to utilize the forward-backward asymmetry. In this paper we calculate the asymmetry for a model in which there is an extra $U(1)$ anomalous symmetry. Furthermore, we show that the asymmetry can be used to impose constraints on the free parameters of the model.

1. Introduction

String theory results suggest that extra $U(1)$ models [1] can be strong candidates to extend the Standard Model (SM). This led us to develop the MiAUMSSM [2], in which the anomalies related to the extra $U(1)$ are cancelled by the Green-Schwarz (GS) mechanism, thus letting the new charges unconstrained. An alternative version of this model which admits spontaneous supersymmetry breaking can be found in [3].

We have already studied the phenomenology of this model using cosmological constraints, such as WMAP data on Dark Matter [4, 5]. We have also studied the radiative decays of the Next to Lightest Supersymmetric Particle in this model [6, 7].

In this paper we aim to use the asymmetry to investigate the detailed properties of the Z' , the new gauge boson associated to the extra $U(1)$ by fixing the charges. We also develop a method that, given the experimental data, can confirm or discard the model in consideration. This method is based on the use of different definitions of asymmetry at the LHC.

At the LHC [8] cuts on the parameter space have to be performed. Each possible cut leads to a different definition of asymmetry at the LHC. In the paper we choose some of these definitions to make our calculations. We will add further details on their explicit form in the related section. The article is organized as follow: in sec. 2 we briefly review the properties of the model that we are going to use, in sec. 3 we discuss the four definitions of asymmetry that will appear in the following and the related calculations. In sec. 4 we show our results.

2. MiAUMSSM

Our model [2] is an extension of the MSSM with an extra $U(1)$ gauge symmetry. The charges of the matter fields with respect to the symmetry gauge groups are given in table 1.

Gauge invariance of the model implies that only three of the $U(1)$ charges are independent. We have chosen Q_Q , Q_L and Q_{H_u} without losing generality. The anomalies induced by this extension are cancelled by the GS mechanism, so there are not further constraints on the charges.

We are going to evaluate the asymmetry of the process $pp \rightarrow e^+e^-$.

	$SU(3)_c$	$SU(2)_L$	$U(1)_Y$	$U(1)'$
Q_i	3	2	1/6	Q_Q
U_i^c	3	1	-2/3	Q_{U^c}
D_i^c	$\bar{3}$	1	1/3	Q_{D^c}
L_i	1	2	-1/2	Q_L
E_i^c	1	1	1	Q_{E^c}
H_u	1	2	1/2	Q_{H_u}
H_d	1	2	-1/2	Q_{H_d}

Table 1. Charge assignment.

3. Four asymmetries at the LHC

The initial LHC state (pp) is symmetric. This implies that the total asymmetry at the LHC is zero if we integrate over the whole parameter space. However the partonic subprocess $q\bar{q} \rightarrow e^+e^-$ is asymmetric. To keep this asymmetry we have to impose kinematical cuts. Each possible way to perform these cuts leads to a different definition of asymmetry at the LHC.

In this work we use the four definitions of asymmetry described in [9]:

$$A_{\text{RFB}}(Y_{e\bar{e}}^{\text{cut}}) = \frac{\sigma(|Y_e| > |Y_{\bar{e}}|) - \sigma(|Y_e| < |Y_{\bar{e}}|)}{\sigma(|Y_e| > |Y_{\bar{e}}|) + \sigma(|Y_e| < |Y_{\bar{e}}|)} \Big|_{|Y_{e\bar{e}}| > Y_{e\bar{e}}^{\text{cut}}} \quad (1)$$

$$A_{\text{OFB}}(p_{Z,e\bar{e}}^{\text{cut}}) = \frac{\sigma(|Y_e| > |Y_{\bar{e}}|) - \sigma(|Y_e| < |Y_{\bar{e}}|)}{\sigma(|Y_e| > |Y_{\bar{e}}|) + \sigma(|Y_e| < |Y_{\bar{e}}|)} \Big|_{|p_{z,e\bar{e}}| > p_{Z,e\bar{e}}^{\text{cut}}}, \quad (2)$$

$$A_C(Y_C) = \frac{\sigma_e(|Y_e| < Y_C) - \sigma_{\bar{e}}(|Y_{\bar{e}}| < Y_C)}{\sigma_e(|Y_e| < Y_C) + \sigma_{\bar{e}}(|Y_{\bar{e}}| < Y_C)} \quad (3)$$

$$A_E(Y_C) = \frac{\sigma_e(Y_C < |Y_e|) - \sigma_{\bar{e}}(Y_C < |Y_{\bar{e}}|)}{\sigma_e(Y_C < |Y_e|) + \sigma_{\bar{e}}(Y_C < |Y_{\bar{e}}|)} \quad (4)$$

The first two asymmetries are defined in the center of mass (CM) frame. The forward-backward asymmetry A_{RFB} [1, 10, 11, 12, 13, 14] has a cut on the rapidity Y of the f/\bar{f} pair (in this work f is an electron), while the one side asymmetry A_O [15, 16] has a cut on $p_{z,f\bar{f}}$, the longitudinal component of the fermionic pair momentum. The other two asymmetries are defined in the lab frame. The variable Y_C is the pseudo-rapidity $-\log(\tan(\theta/2))$: in this case the kinematical cut is on the angles of the outgoing particles with respect to the beam direction in the lab frame. The central asymmetry A_C [17, 18, 19, 20, 21] is calculated integrating in the angular region centered on the axis othogonal to the beam, while the edge asymmetry A_E [22] is defined in the complementar region.

4. Calculations and results

We calculate the value of the cuts that maximizes the significance of each definition of asymmetry, then we use these best cuts to evaluate the asymmetries in different ways, i.e. as a functions of two free charges keeping the third fixed to 0 and as a function of the three charges. We have set the mass of the Z' boson at 1.5 TeV to permit a direct comparison with the results of [9].

4.1. Optimal cuts

As shown in [9] the asymmetry magnitude is not a good function to optimize the observable. A better choice is, instead, the statistical significance:

$$Sig \equiv A\sqrt{\mathcal{L}\sigma} \quad (5)$$

where A can be any of the previously defined asymmetries, \mathcal{L} is the LHC integrated luminosity, which we take to be 100 fb^{-1} and σ is the total cross section.

In figure 1 we show the results associated to the significance for all the asymmetry definition that we use in the “on peak” region, that is $M_{Z'} - 3\Gamma_{Z'} < M_{e^+e^-} < M_{Z'} + 3\Gamma_{Z'}$.

The best cuts are those that maximize the significance. We list them in the table 2

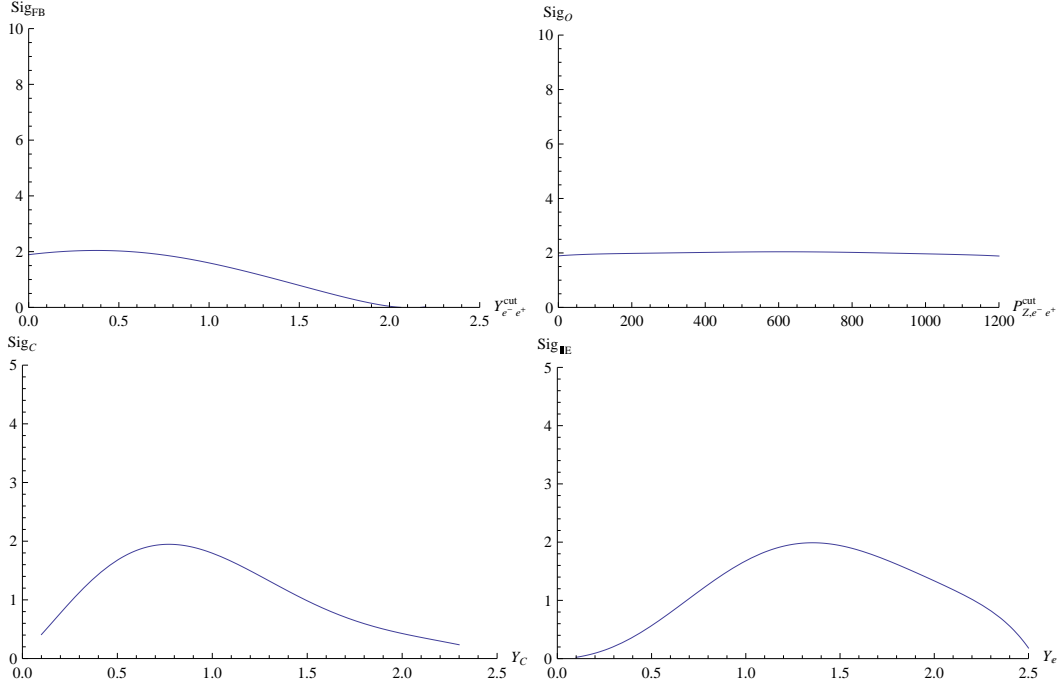


Figure 1. Significance of the four definitions of asymmetry as a function of the corresponding cut for for on-peak events

	A_{RFB}	A_O	A_C	A_E
Best cut	$Y_{f\bar{f}}^{cut} = 0.4$	$p_{z,f\bar{f}}^{cut} = 580 \text{ GeV}$	$Y_C = 0.8$	$Y_e = 1.4$

Table 2. Best cuts for the on-peak e^+e^- asymmetries

4.2. Asymmetry calculations

Using the best cuts we have studied the dependence of the asymmetry from couples of the free charges. There are three possibilities for the couples of the charges: $Q_{H_u} - Q_L$ ($Q_Q = 0$), $Q_{H_u} - Q_Q$ ($Q_L = 0$) and $Q_L - Q_Q$ ($Q_{H_u} = 0$). For the sake of brevity, in figures 2 and 3 we show only the plots obtained keeping $Q_L = 0$.

4.3. Charges constraints

To impose constraints on the charges, we have calculated the asymmetry dependence from the three charges. It turns out that the asymmetries are rational functions of 4th order in the

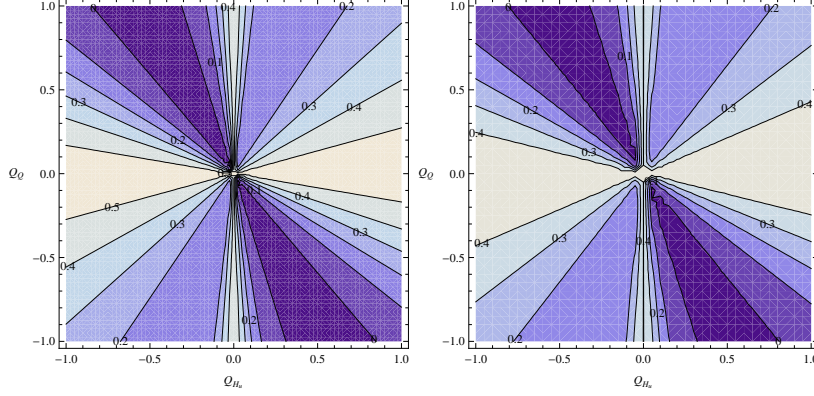


Figure 2. Results with the asymmetries for $Q_L = 0$ for the best cuts. The left image is A_{RFB} , the right image is A_O

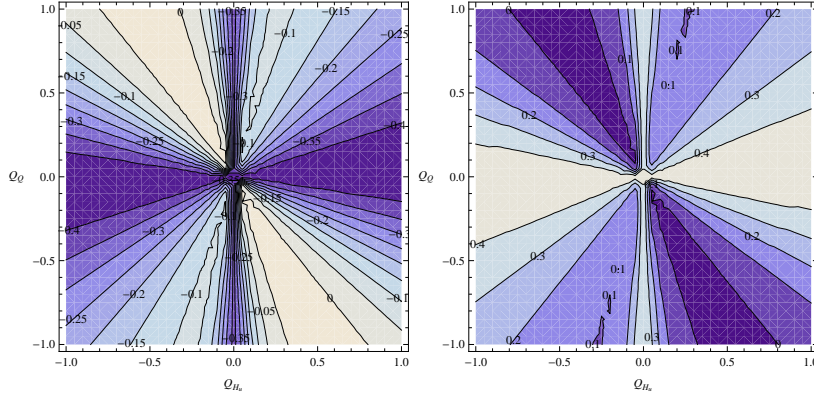


Figure 3. Results for the asymmetries with $Q_L = 0$ for the best cuts. The left image is A_C , the right image is A_E

charges, so we use the following fit function:

$$A = \frac{\sum_{i,j,k=0}^n a_{ijk} (Q_{H_u})^i (Q_Q)^j (Q_L)^k}{\sum_{i,j,k=0}^n b_{ijk} (Q_{H_u})^i (Q_Q)^j (Q_L)^k} \quad (6)$$

with $i + j + k = n \leq 4$. We have calculated this expansion for the previous four asymmetry definitions that we have considered so we have them expressed as a functions of the charges. We do not show here their complete expression, that can be found in However, if a deviation from the asymmetry associated to the SM asymmetry is discovered, this expressions can be used as a system of four equation of the three variables Q_{H_u} , Q_L and Q_Q . Solving this system using the experimental values of the asymmetry will give constraints on the charges and a consistency check of the model.

5. Conclusion

We have studied four different definitions of asymmetry at the LHC, namely the forward-backward, the one-side, the central and the edge asymmetries in the channel $pp \rightarrow e^+e^-$.

To perform this study we have written a numerical code that finds the value of the cut that maximizes the significance of each definition of asymmetry. After that, we have calculated the value of the four asymmetries as functions of couple of charges, keeping one of the three free

charges of our model fixed to 0.

Finally, we have calculated the functional dependence of the asymmetries from the three charges using an expansion in rational functions. If an asymmetry of this type will be found at the LHC this expansions could give constraints on the free charges of the model.

So we have completely characterized the asymmetry of the MiAUSSM with a procedure that can be replied for every other model of physics beyond the SM.

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